Composition and properties of soil humus in a mixed forest of *Cunninghamia lanceolata* and *Tsoongiodendron odorum*

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Abstract: This study was conducted in Xinkou Experimental Forestry Farm of Fujian Agricultural and Forestry University, Sanming, Fujian Province in January 1999. Taking pure stand of Chinese fir as control, the authors measured and studied the content of organic carbon, content of humic acid (HA), ratio of HA to fulvic acid (FA), and the characteristics of infrared light spectrum and visible light spectrum of soil humus in the mixed forest of Chinese fir and Tsoong' tree. Compared to humus composition in the pure stand of Chinese fir, the content of soil organic C, HA content, and the E_4 value of HA for different layers of soil, except for the ratio of HA to FA, showed a significant increase in the mixed forest, while the ratios of E_4 to E_6 had a little decrease. The infrared light spectrum of humic acid had an absorptive peak at 1650 cm^{-1}. It is concluded that the levels of humification and aromaticity of soil humus are higher in the mixed forest, which is favorable for the improvement of soil structure and nutrient supply, thus improving the soil fertility to a certain degree.

Keywords: Chinese fir; Tsoong's tree; Mixed forest; Soil humus fraction; Optical properties
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Introduction

Chinese fir (*Cunninghamia lamcealata* (Lamb.) Hook) is one of the most important plantation tree species in China in terms of planting area, yield and timber usage. The continuous monoculture of Chinese fir is a traditional silvicultural practice. However, yield decline and soil degradation have widely occurred in Chinese fir stands with such a forestry practice. This problem has caused considerable attentions.

In order to preserve long-term site productivity or to restore soil fertility in a degraded site, mixing broad-leaveds in a stand have been tried as silvicultural measures (Yang 1998; Yu 1996; Zheng *et al.* 1998). Some characteristics of soil feritlity have been reported in the mixed stands of Chinese fir and several broad-leaveds (Yu 1996; Yang *et al.* 1996). However, study on composition and propertie of soil humus in these forests was limited.

Soil humus was involved in many of the soil chemical, physical and biological processes determining the capacity of a soil to support plant growth, and, an assessment of humus properties is critical to define overall soil quality. Although there was great interest in the role of humus in soil nutrition and ecosystem function, there have been few studies providing unequivocal identification and quantification of humus because of the heterogeneous and polydisperse nature of humic substances, and the complexity of the inter- and intramolecular reactions. In this study, we focused attention on the organic C, humic and fulvic acid, and optical properties of humus to compare the difference of humic substances extracted from soils in a mixed forest of Chinese fir with Tsoong' tree (*Tsoongiodendron odorum* Chun) and an adjacent pure Chinese fir forest.

Sites

The study was conducted in Xiaohu experimental area of Xinkou Experimental Forestry Farm of Fujian Agricultural and Forestry University, Sanming, Fujian Province (26°11′30″ N, 117°26′00″ E). The sites are on the slope of 35° in facing northeast in the mixed forest of Chinese fir and Tsoong' tree, and in the pure Chinese fir stand, respectively. The climate is characterized by sub-tropical monsoon, with an annual mean temperature of 19.1 °C, an annual mean precipitation of 1 749 mm, an annual mean evaporation of 1 585 mm, an annual mean relative humidity of 81%, and a frost-free period of 300 d. The soil is red soil derived from sandy shale.

The mixed forest and pure stand were established with seedling in 1973, with an initial planting density of 3 000 stems per hectare. The mixed pattern is strip spacing, three rows of Chinese fir spaced by one row of Tsoong' tree. At the time of survey, the pure stand (at age of 27) had a density of 1 100 stems per hectare, with a crown density of 0.80 and undergrowth coverage of 95%. The mean tree height and diameter at breast height were 19.61 m and 23.6 cm respectively. In the surface soil (0-20 cm), the contents of hydrolysable N, available P, and available K were 86.21 mg kg^{-1}, 4.92 mg kg^{-1} and 82.31 mg kg^{-1},

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respectively. The mixed stand had a density of 907 stems per hectare for Chinese fir and 450 stems per hectare for Tsoong' tree. The mean tree height and DBH were 20.88 m and 25.1 cm for Chinese fir, 17.81 m and 17.0 cm for Tsoong' tree, respectively. The crown density was of 0.95 and the undergrowth coverage was of 80%. The contents of hydrolysable N, available P, and available K in the top-soil at 0-20 cm, were 106.80 mg kg^{-1}, 5.42 mg kg^{-1} and 92.65 mg· kg^{-1}, respectively.

Materials and methods

Soil collection

Six plots (20 m x 20 m) were established in each stand. For determination of soil humus, soil samples were collected in January 1999 from five sampling locations following a sigmoid route across each plot. Soil was divided into three layers, 0-20 cm, 20-40 cm and 40-60 cm. Soil samples at the same layer in each plot were equally mixed.

Soil analysis

Soil organic C content was determined by the procedure of heating oxidation with the mixture of $K_2Cr_2O_7$ and H_2SO_4 at (180±5) °C for five minutes. For determination of soil humus fractionation, each sample was extracted with the mixture of 0.1 mol/L NaOH and 0.1 mol L^{-1} $Na_4P_2O_7$ in a airtight container, which was made of polyethylene and filled with nitrogen, at (20±1) °C for 16 h, then the suspension was filtrated the next day. 10-25-mL alkaline extract was subsampled from the filtrate and added with 6 mol/L HCl to pH 1.5, vaporized; then humus C content was determined with the oxidizing method. Another 10-50-mL alkaline extract was subsampled, added with 6 mol/L HCl to pH 3, heated at (80±1) °C for half an hour, cooled, and then centrifuged the next day. HA precipitate was obtained and dissolved in 0.05 mol/L NaOH. 10-25-mL subsample dissolved in 0.05 mol/L NaOH was made to determine humic acid C content. C content of all samples was also determined as the method described above. In addition, in order to purified humic acids, the raw humic acids were treated with 0.5%HF: 0.5%HCl (removal of SiO_2) and dissolved in 0.05 mol/L NaOH, dialysed until no Cl^- can be examined by 1% $AgNO_3$ solution, then dialysed with a self-made electric dialysed equipment to pH (6.5-7.0) and freeze-dried (Kononoba 1966). The values of E_4 and E_6 were determined by dissolving HA in 0.05 mol/L $NaHCO_3$ and measuring optical densities at 465 nm and 665 nm with an UV-120-02 ultraviolet–visible spectrometer (Chen *et al.* 1977). FT-IR spectra were obtained from KBr-pellets of freeze-dried samples on a Perkin-Elmer-Spectrum-2000 FTIR spectrophotometer (Takacs *et al.* 1999).

Statistical analysis

Significant differences in various parameters of soil humus (e.g. soil organic C, humic C, percentage HA and FA) at each soil layer between the mixed and pure stands were determined by Student's *t*-tests, which was at a significant level of 0.05.

Results

Soil humus composition

The contents of organic C and humus C in the topsoil of the mixed forest were 19% and 36% higher than those of the pure stand, respectively. The degree of humification, an index of soil humus property referred to the proportion of soil humic acid (HA) in total soil C, was 1.25 times, and the content of humic acid was 1.49 times, as much as those of the pure stand, respectively. In addition, HA/FA ratio in the surface soil of the mixed forest was higher than that of the pure stand, although this difference was not statistically significant (Table 1). The same trends occurred in soil depths of 20-40cm and 40-60 cm.

Table 1. Composition and optical property of soil humus (mean±SE, n=6)

Stands type	Soil layer /cm	OM-C /g· kg^{-1}	Humus-C /g· kg^{-1}	HA-C /g· kg^{-1}	FA-C /g· kg^{-1}
	0-20	15.68±0.47*	8.60±0.28*	2.47±0.20*	6.13±0.18*
Mixed forest	20-40	8.70±0.45*	5.65±0.29*	0.90±0.06*	4.75±0.09*
	40-60	6.37±0.24 *	3.67±0.51	0.52±0.05*	3.15±0.15
	0-20	13.18±0.39	6.33±0.24	1.66±0.18	4.67±0.22
Pure forest	20-40	5.84±0.42	3.58±0.38	0.44±0.06	3.14±0.27
	40-60	4.70±0.27	2.75±0.47	0.22±0.03	2.53±0.12

Stands type	Soil layer /cm	HA (%)	FA (%)	HA/ FA	E_4	E_4/E_6
	0-20	15.75±0.05*	39.09±0.09*	0.40	0.36±0.03*	5.26
Mixed forest	20-40	10.34±0.07*	54.60±0.10*	0.19	0.30±0.02*	6.12
	40-60	8.16±0.03*	49.45±0.08	0.17	0.21±0.01*	6.50
	0-20	12.59±0.09	35.43±0.11	0.36	0.27±0.02	5.41
Pure forest	20-40	7.53±0.05	53.77±0.09	0.14	0.14±0.01	6.36
	40-60	4.68±0.07	53.83±0.06	0.09	0.11±0.01	6.71

Notes: OM-C, HA-C, and FA-C stand for carbon content of organic matter, humic acid, and fulvic acid respectively. HA-humic acid, FA stand for fulvic acid. HA%=HA-C/MO-C×100, FA%= FA-C/MO-C×100. HA/FA is ratio of carbon content of humic acid to fulvic acid. E_4 and E_6 are extinct coefficient of HA at 465 nm and 665 nm, respectively. Significant differences (p<0.05) in the same soil layer between the mixed and pure forests are indicated with an asterisk.

Optical properties of soil humus

The E_4 value (the optical density at 465 nm wavelength) of humic acid in the surface soil of the mixed forest was 33% higher than that of the pure stand, while lower E_4/E_6 ratio of soil HA was observed in the mixed forest (Table 1).

The FT-IR spectra of soil humic acids showed structural difference of HAs from the two stands (Fig. 1). The spectra showed the following absorbances: broad-leaved band in the 3 350-3 450 cm^{-1} region, due to H-bonded OH stretch; sharp peaks at 2 920 cm^{-1}, attributed to aliphatic C-H stretch; broad-leaved bands at 1 640-1 665 cm^{-1}, originated from quinone C=O and aromatic C=C stretch; bands at 1 380-1 390 cm^{-1}, produced by COO^- groups and/or aliphatic C-H stretch; absorption bands around 1 240 cm^{-1}; produced by C-O stretch and/or O-H deformation vibrations of carboxyl groups, sharp peaks around 1 050 cm^{-1} due to silicates and/or polysaccharides; The absorption bands at 465 cm^{-1} are probably due to the present of silicate. Most infrared spectra of soil HAs in the mixed forest were coincident with those in the pure stand (Fig.1), it is suggested that their HAs had similar molecular structure and functional groups (Liu 1990). However, the former having characteristic absorption peak around 1 720 cm^{-1} was representative of its undissociated COOH and COOR groups, absorption bands at 1 650 cm^{-1} also indicated higher degree of polycondensation.

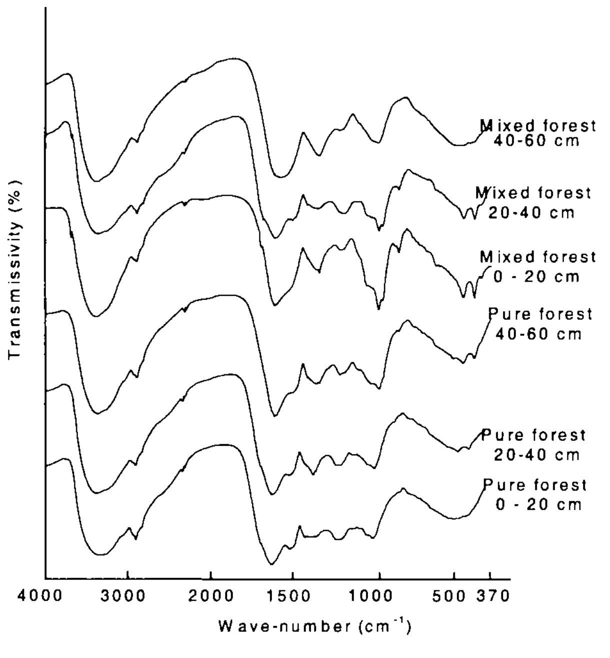

Fig. 1 Infrared absorption spectra of soil HA at three soil layers in the mixed and pure forests

Discussion

Soil humus fraction and property

Soil organic matter content strongly affected soil fertility on nutrient cycling and on the physical-chemical and biological properties of soils. Humus was the most important component of soil organic matter. Also, soil humus represents a major pool of C in forest ecosystems. The chemical composition of humus was understood poorly because of the complexity of the soil-plant interaction and the lack of reliable analytical methods. The higher humic C content in soils of mixed forest suggested that there are more favorable external environmental conditions for the formation of soil humus in mixed forest than in pure forest.

The decomposition and transformation of organic material in soils ultimately resulted in the formation of fulvic acids (FAs) and humic acids (HAs). Fulvic and humic acids were important components in soil systems, and they were able to strongly combine both essential and toxic elements. In particular, the content and characteristic of soil HA usually reflected humus quality. In this study, HA/FA ratios in the mixed and pure forests were 0.40 and 0.36 respectively and both less than 0.5, which was similar to the results of Yang (1996) for soil humus in the pure and mixed Chinese fir stands in Nanping. The low HA/FA ratio in this study agreed with the common findings (HA/FA ratio less than 0.45) in red soils of subtropics (Xiong *et al.* 1990).

Optical properties of soil HA were often used to estimate its molecular structure. There were higher E_4 value and lower E_4/E_6 ratio in the mixed forest, compared with the corresponding parameter in the pure stand. Infrared spectrum analysis had also exhibited relatively simple chemical structure of soil humus in the pure Chinese fir stand.

The composition and property of forest soil humus were closely related to decomposability of aboveground litter and fine roots (Yang *et al.*1997; 1998). However, it was impossible to quantify the individual contribution of each of these sources to humus formation. Differences in litter quality in both stands played a major role in differentiating the humus. Compared with broadleaves, needle litter with lower N concentration, higher C/N ratio, and a higher content of decay-resistant substrates (e.g., lignin and tannins) decomposed slowly and allowed for the accumulation of mor humus with a low degree of humification (Berg *et al.* 1996). Especially, the amount of acid insoluble (AIS) material in the litter would obviously influence the proportion of the litter that became humus. In forest floor of the mixed forest, there was more mull humus. As well, in progressing from mor humus to mull humus, there was a gradual increase in the degree of decomposition. This, in turn, resulted in greater nutrient availability. Overall, the type of humus greatly influenced soil fertility.

Soil humus function

The importance of humus for the nutrition of forests had been recognized for a long time. Gregorich *et al.* (1994) proposed two essential functional roles of humus, which was soil structure and nutrient storage. The addition of humic substances to soils was effective in increasing the amount and size of water-stable aggregates, especially in soils with low total organic matter contents (Tisdall and Oades 1982; Angers and Mehuys 1989). A better soil

structure in the mixed forest than that in the pure stand could be testified by a higher content of soil water-stable aggregates and a higher level of total porosity. Obviously, the improvement of soil structure had a favorable effect on soil aeration and water permeability, which benefited trees' growth. On the other hand, humus might also be view as a nutrient sink, especially for nitrogen. This nutrient reserve was critical to long-term site fertility, and helped to buffer the site against disturbances that might lead to nutrient depletion. In addition, intense biological activity resulted in humus oxidation to CO_2 and disorganization of the organo-mineral complexes, and then available nutrients were released correspondingly, which improved short-term productivity.

In view of the ways of soil humus affecting soil fertility, proper management of this resource entailed two rather divergent considerations, that was, to conserve soil humus in sites to protect long-term site productivity, and to manipulate soil humus to increase nutrient release for short-term productivity. Growing mixtures of species might balance the two aspects, particularly if hardwoods were interplanted with conifers (Yang 1998). This mixture effect might be the result of the mycorrhizal associates of some species, which is favorable to access organic forms of nutrients. Higher nutrient availability found in Chinese fir and Tsoong's tree mixed forests seemed that soils in the mixed forest provided better nutrient supply for the trees and this silvicultural pattern could avoid soil degradation of the pure Chinese fir forest.

References

Angers, D.A. and Mehuys, G.R. 1989. Effects of cropping on carbohydrate content and water stable aggregation of a clay soil [J]. Can. J. Soil Sci., **69**: 373-380.

Berg, B., Ekbohm, G., Johansson, M.B., *et al.* 1996. Maximum decomposition limits of forest litter types: a synthesis [J]. Can. J. Bot., **74**: 659-672.

Chen, Y., Senesi, N. and Schnitzer, M. 1977. Information provided on humic substances by E_4/E_6 ratio [J]. Soil Sci. Soc. Am. J., **41**: 352-358.

Gregorich, E.G., Carter, M.R., Angers, D.A., *et al.* 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils [J]. Can. J. Soil Sci., **74**: 367-385.

Kononoba, M.M. 1966. Analytical Methods: Quality and Character [M]. Beijing: Science Publishing House.

Liu Changhuai and Luo Ruying. 1990. Chemical characteristics of humus in forest soils of Nanjing-Zhenjiang Hills [J]. Journal of Nanjing Forestry University, **14** (1): 1-6.

Sun Duo. 1996. A biological way to prevent site degradation of Chinese fir plantation-residue management cultivation [D]. Ph. D. Dissertation, Nanjing Forestry University, p42.

Takacs, M. and Alberts, J.J. 1999. Changes in chemical composition, FTIR and fluorescence spectral characteristics of humic acids in peat profiles [J]. Spec. Publ.- R. Soc. Chem., **247**: 169-177.

Tisdall, J.M. and Oades, J.M. 1982. Organic matter and water-stable aggregates in soils [J]. J. Soil Sci., **33**: 141-163.

Xiong Yi and Li Qingkui. 1990. Soils in China [M]. Beijing: Science Publishing House, p390-394.

Yang Yusheng, He Zhongming, Yu Xintuo, *et al.* 1997. The effect on the controlled burning to the soil humus and fertility in different forest stands [J]. Scientia Silvae Sinicae, **33** (Supplement 1): 31-38.

Yang Yusheng. 1998. Sustainable Management of Chinese Fir Forest [M]. Beijing: China Forestry Publishing House, p209-220.

Yang Yusheng, Qiu Rrenhui and Yu Xintuo. 1999. Study on soil humus and fertility characteristics in 29-year-old plantations of Chinese fir of different rotations [J]. Scientia Silvae Sinicae, **35** (3): 116-119.

Yang Yusheng, Yang Lunzheng and Yu Xintuo. 1996. Changes in composition and properties of soil humus following replacement of broad-leaved forest by Chinese Fir plantation [J]. Journal of Fujian College of Forestry, **16**(2): 101-104.

Yu Tianren. 1987. Chemical Principle of Soil [M]. Beijing: Science Publishing House, p110-115.

Yu Xintuo. 1996. Silviculture of Chinese fir [M]. Fuzhou: Fujian Science and Technology Publishing House, p311-313.

Zheng Yushan and Ding Yingxiang. 1998. Effect of mixed forest of Chinese fir and Tsoong' tree on soil properties [J]. Pedosphere, **8**(2): 161-168.